Proceedings of the 12th International Conference on
Aluminium Alloys, September 5-9, 2010, Yokohama, Japan

pp. 1207-1212

Formability of AA5083 Aluminum Alloy Sheets Produced by Controlled Rolling

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The microstructure and mechanical properties of AA5083 aluminum alloy sheets consisting of well developed β-fiber texture were investigated. In order to maintain rolling textures after final annealing, the materials were rolled isothermally at 623K by making use of heated rolls and reheating process every pass up to final thickness of 1mm. The isothermal rolled sheets consisted of fine subgrain structures through the thickness with a high proportion of low angle boundary less than 15°. Tensile properties showed anisotropy clearly regarding elongation and Lankford value. In the isothermal rolled sheets, the elongation of 0° to rolling direction was below 20% and Lankford value of 45° to rolling direction was over 1.5. Therefore, the average Lankford value showed 1.0. The yield strength of the isothermal rolled sheets was about 40% higher than that of the cold rolled sheets because of subgrain structures. The low ductility of 0° to rolling direction on the isothermal rolled sheets seemed to reduce drawability at room temperature. The warm drawability of the isothermal rolled sheets was superior to the cold rolled sheets because of increasing ductility and keeping higher strength than the cold rolled sheets.

Keywords: *aluminum alloys, Lankford value, drawability, texture, controlled rolling*

1. Introduction

Lankford value has been used as an indicator on formability of sheet materials. It is well known that drawability has strong relationship with Lankford value which is influenced by texture. Low-carbon steel sheets show the *γ*-fiber({111}<011>~{111}<112>) after annealing [1], then high Lankford value and good deep-drawability [2] are available in the sheets. It is predicted by Taylor model that {111}<uvw> components yield high Lankford value over 1.0 [3]. Meanwhile, main component in O-temper of aluminum alloy sheets is a {001}<100> Cube component which indicates low Lankford value predicted by Taylor model as shown in Fig.1. In aluminum alloy sheets, the texture consisted of the β-fiber ({011}<211>–{123}<634>–{112}<111>) after cold rolling [4]. It was expected according to Taylor model that the β-fiber increased Lankford value of 45° to rolling direction. Such cold rolled sheets are not suitable for press forming because of low ductility. If a sheet is prepared with thermal stability in microstructure, high Lankford value with adequate ductility is gained by remaining β-fiber after a specified heat treatment. The thermal stability of AA5083 aluminum alloys has been investigated by making use of plane strain compression test [5]. Due to this study, it was found that AA5083 aluminum alloy sheets deformed at not lower than 623K and under control of strain rate in 5/s and below have the property of thermal stability. In the present work, AA5083 aluminum alloy sheets were prepared under control of temperature and strain rate according to the above results of the plane strain compression test. These materials were also investigated about microstructures and drawing formability comparing with conventional AA5083 aluminum alloy sheets produced by cold rolling.

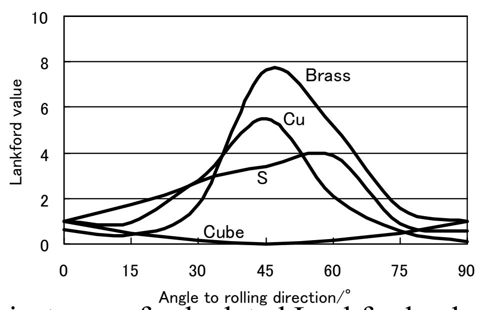

Fig.1, Anisotropy of calculated Lankford values.

2. Experimental procedures

Composition of AA5083 used in this work is given in Table 1. The alloy AA5083 was cast into slabs by a standard semi-continuous direct chill technique. The slab was homogenized at 738K for 43.2ks followed by machining with dimensions of 30mm high, 170mm wide and 170mm long. The rolling equipment used in this work had two ϕ260mm work rolls mounted eight cylindrical heaters per roll[9)] to keep roll temperature near sample temperature. In this experiment, the peripheral velocity of the work rolls was 5m/min, and the rolls were heated at 643K ± 15K in order to manufacture sheets isothermally to the final thickness of 1mm. The above material machined was rolled at 623K with re-heating at 623K for about 900s after every pass. Average strain rate of every pass was calculated roughly by the following equation [6].

$$\dot{\varepsilon} = \frac{U_R}{\sqrt{R' h_0}} \times \frac{2\sqrt{2r}}{2-r} \tag{1}$$

Here, U_R is the peripheral velocity of roll (m/s), R' is the radius of roll (m), h_0 is the sample thickness before rolling (m) and r is the rolling reduction per pass. Then, the average strain rate per pass should be under 5/s. Commercial machine oil was used in the isothermal rolling process. In order to prepare conventional materials, hot rolling, intermediate annealing and cold rolling were carried out. Final annealing was carried out to the isothermal rolled samples and cold rolled samples at 623K for 3600s.

Microstructure was observed using an optical microscope and a transmission electron microscope (TEM). Misorientation angles between grains were measured using electron backscattered diffraction (EBSD) equipment with a scanning electron microscope (SEM). Measurement points on EBSD analysis were set at an interval of 0.5µm. X-ray diffraction method was used to describe incomplete pole figures, and orientation distribution functions (ODFs) were calculated from three incomplete pole figures of {111}, {110} and {100} by the harmonic method [7]. The mechanical properties of the samples after the final annealing were investigated. Tensile test specimens were got from the orientations of 0°, 45° and 90° to the rolling direction. Drawing formability at room temperature was investigated according to the conditions given in Table 2. Additionally, warm drawing test shown in Table 3 was carried out with a punch of 50mm in diameter in blank holding force of 6kN. In order to distinguish warm drawability between the isothermal rolled sheets and conventional sheets, the punch of the test machine was not cooled. Therefore, the punch temperature was about 60K lower than specimen temperature.

Table 1, Chemical composition of specimens (mass%).

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
0.04	0.05	<0.01	0.63	4.38	0.16	<0.01	0.02	Bal.

Table 2, Drawing test condition at room temperature.

Lubricant	Castrol No.700 (Grease)
Punch	ϕ50mm (flat)
Die	ϕ53mm
Blank diameter	ϕ110mm
BHF	10kN
Punch speed	120mm/min

Table 3, Drawing test condition at warm temperature.

Lubricant	MOLYKOTE (Molybdenum disulphide)
Punch	ϕ50mm (flat)
Die	ϕ53mm
Temperature	473-573K
BHF	6kN
Punch speed	120mm/min

3. Results

3.1 Isothermal rolling condition

Sample temperature was measured during heating in a furnace, and immediately after rolling. Sample thickness was also measured after rolling in order to derive strain rate every pass. The rolling process was carried out in the range from 613K to 623K, and the strain rate per pass was kept below 5/s through the process. Sample temperature maintained to a final thickness of 1mm as the heated rolls were used.

3.2 Microstructures and textures

Fig. 2 shows optical micrographs in L-LT section and TEM images after the final annealing in order to compare the isothermal rolled sheet (IR) with the cold rolled sheet (CR). In optical micrographs, it is found that the cold rolled sheet consists of equiaxial grains about 30μm in diameter, whereas the isothermal rolled sheet maintains rolled structure. In TEM images, it is revealed the isothermal rolled sheet consists of fine grains whose average diameter is approximately 3μm. Fine particles would contain manganese or Chromium as Al_6Mn and $Al_{18}Cr_2Mg_3$ by reference to the previous work [8].

Fig. 3 shows misorientation angle histograms taken from SEM-EBSD measurements. The measured area in this work was 100×100μm. The isothermal rolled sheets have a high proportion of low angle boundary less than 15°, whereas the cold rolled sheets show a lower proportion of the low angle boundary. According to the above results, it is clear that the isothermal rolled sheets consists of subgrain structures.

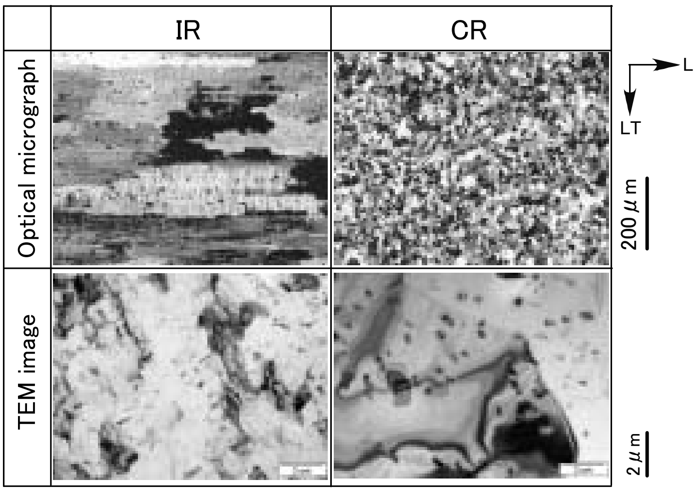

Fig. 2, Optical and TEM micrographs after annealing at 623K for 3.6ks.
IR: isothermal rolled sheets, CR: cold rolled sheets.

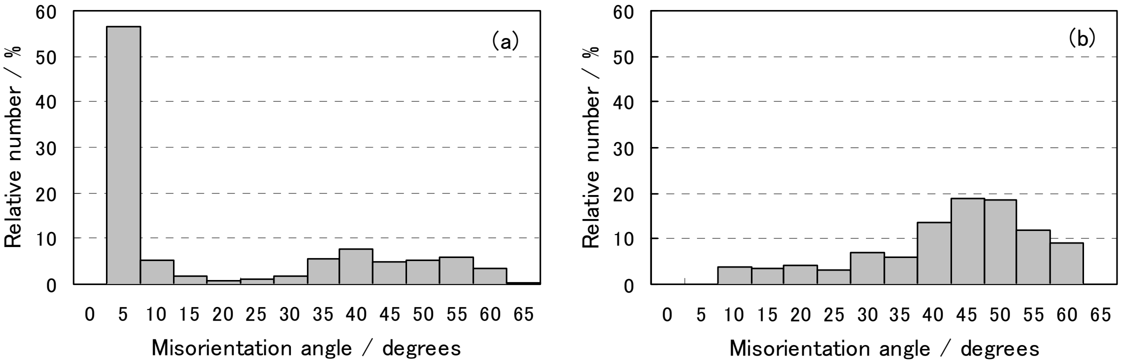

Fig. 3, Misorientation angle histograms after annealing at 623K for 3.6ks of isothermal rolled sheets (a) and cold rolled sheets (b).

Fig. 4 gives the ODFs at the surface and center layers of the materials after the final annealing. In the isothermal rolled sheets, the β-fiber, especially {011}<211> Brass component is recognized clearly through the thickness of it. The cold rolled sheets have a weak peak of {001}<100> Cube component. In other words, the texture of the cold rolled sheets was randomized after recrystallization.

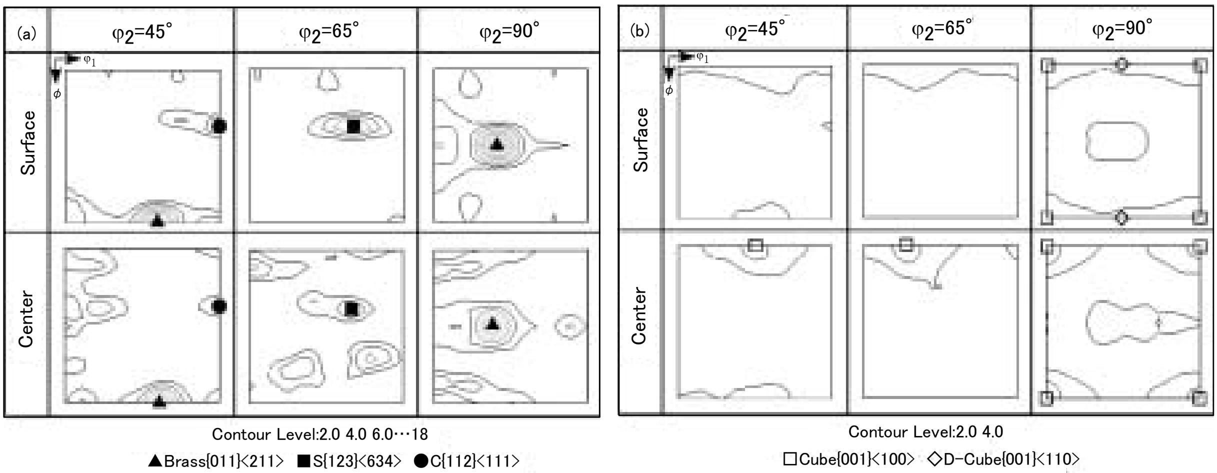

Fig. 4, ODFs after annealing at 623K for 3.6ks of isothermal rolled sheets (a) and cold rolled sheets (b).

3.3 Tensile properties

Table 4 summarizes the tensile properties after the final annealing. The yield strength of the isothermal rolled sheets is about 40% higher in orientations of 0° and 90° to rolling direction than that of the cold rolled sheets. The properties of the isothermal rolled sheets on ductility and Lankford value measured at 10% elongation show anisotropy whereas the cold rolled sheets tend to be isotropic. Regarding the isothermal rolled sheets, the elongation of 0° to rolling direction is below 20% and Lankford value of 45° to rolling direction is very high. Due to this property on Lankford value, the average value is over 1.0. The average Lankford value of the cold rolled sheets is lower than that of the isothermal rolled sheets.

Table 4, Mechanical properties after 623K annealing.

Condition	Angle to RD	Tensile strength (MPa)	Yield strength (MPa)	Elongation (%)	r-value	ave.r	Δr
5083 IR	0°	351	207	16	0.41	1.09	-0.91
	45°	328	192	26	1.54		
	90°	348	204	21	0.85		
5083 CR	0°	315	149	24	0.76	0.67	0.13
	45°	302	145	28	0.60		
	90°	300	145	25	0.70		

3.4 Drawing formability

At room temperature, the drawability of the isothermal rolled sheets seems to be superior to the cold rolled sheets as shown in Fig. 5. Breaking points in this test were different between the two materials. The cold rolled sheets broke at corner of the punch. Meanwhile, the isothermal rolled sheets broke at side surface of 0° to rolling direction. The drawability at room temperature will be discussed later. The limiting draw ratio (LDR) measured between 473K and 573K is shown in Fig. 6. Up to 523K, the isothermal rolled sheets show higher LDR than the cold rolled sheets. Then, at 573K, the both materials show same level on LDR. Fig. 7 indicates the effect of blank holding force (BHF) at 523K. Generally, low BHF leads wrinkling matter and high BHF reduces DR [9]. In the cold rolled sheets, the range of BHF to carry out drawing successfully is very limited at the draw ratio of 2.2. On the other hand, the isothermal rolled sheets have somewhat large range of BHF to carry out drawing successfully at the draw ratio of 2.3. The above results show the isothermal rolled sheets have good drawability at 523K or so. In the warm drawing, the break points of the isothermal rolled sheets were at corner of the punch.

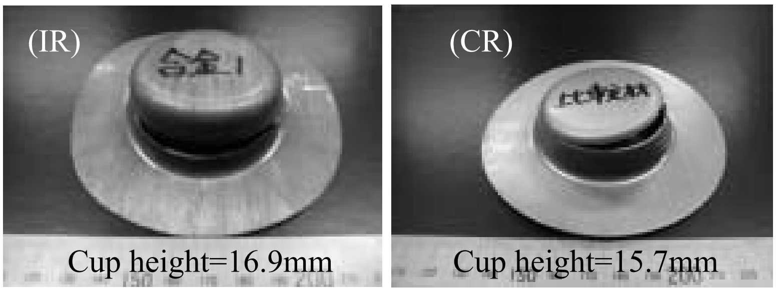

Fig. 5, Appearance of specimens drawn at room temperature. Cup height: IR=16.9mm, CR=15.7mm.

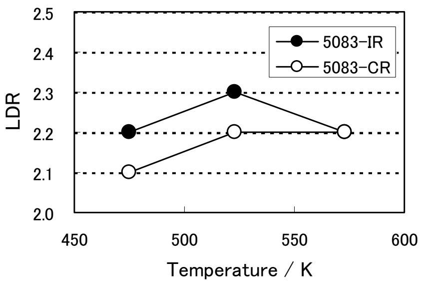

Fig. 6, Limiting draw ratio at warm temperature. IR: isothermal rolled sheets, CR: cold rolled sheets.

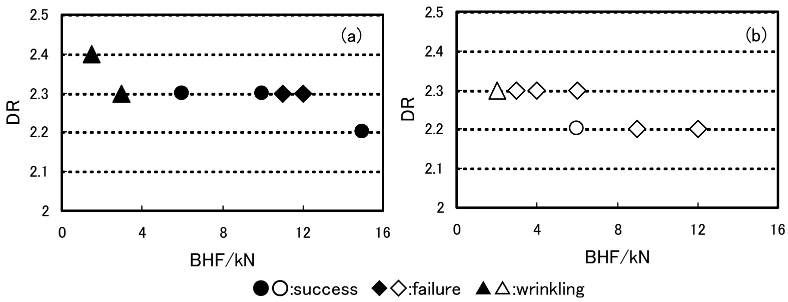

Fig. 7, Warm drawability at 523K of isothermal rolled sheets (a) and cold rolled sheets (b).

4. Discussions

In the present work, it was found that the isothermal rolling is able to form β-fiber strongly through the thickness of a sheet. The materials produced by the isothermal rolling maintained the β-fiber after the final annealing, whose texture made Lankford value of 45° to rolling direction increase whereas the anisotropy of mechanical properties became marked. This trend agrees with the previous work [3] which argued the anisotropy of Lankford value by making use of Taylor model. Regarding the ductility, it was found that the elongation of 0° to rolling direction on the isothermal rolled sheets decreases significantly. In the drawing test at room temperature, the reason of breaking point at side surface of 0° to rolling direction on the isothermal rolled sheets seems to be ascribable to the above decrease of the elongation. The property of LDR at room temperature on the isothermal rolled sheets was not superior to the cold rolled sheets, which may be related to the small ductility of 0° to rolling direction. Further examination should be required to consider the relationship between tensile properties and drawability at room temperature. The breaking of the isothermal rolled sheets occurred at corner of the punch in the warm drawing. In order to consider the change on above breaking points, tensile properties of 0° to rolling direction were checked (Fig. 8) at elevated temperatures. The ductility of the isothermal rolled sheets increases in a temperature range over 400K, which seems to be a reason to change location of break point at the warm drawing. The isothermal rolled sheets have higher tensile strength up to 523K than the cold rolled sheets. This tendency may lead the isothermal rolled sheets to good warm drawability up to 523K. By making use of 1.5mm thickness sheets rolled isothermally, a large member shown in Fig. 9 was formed successfully in warm forming at around 550K by two types of die.

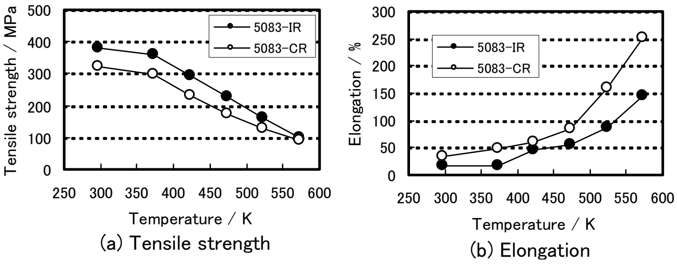

Fig. 8, Tensile strength (a) and elongation (b) versus tensile temperature. IR: isothermal rolled sheets, CR: cold rolled sheets.

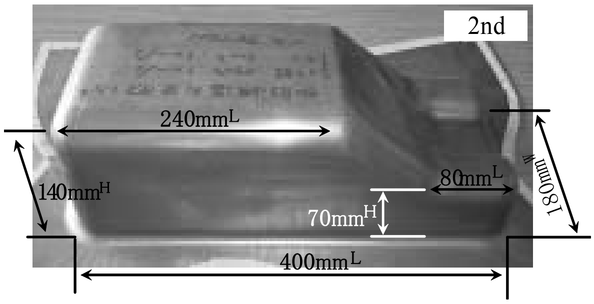

Fig. 9, The appearance of the molded article at the 1st and 2nd stage by isothermal rolled sheets.

5. Conclusions

The microstructures and drawing formability of AA5083 aluminum alloy sheets prepared by isothermal rolling which controls temperature and strain rate were investigated comparing with conventional AA5083 aluminum alloy ones produced by cold rolling. The conclusions obtained are as follows.

(1) Due to the isothermal rolling under the control of sample temperature and strain rate, the β-fiber, especially {011}<211> Brass component is formed clearly through the thickness of a sheet after 623K annealing.

(2) The isothermal rolled sheets have anisotropy on mechanical properties, which show the elongation of 0° to rolling direction is below 20% and Lankford value of 45° to rolling direction over 1.5. And, the yield strength of the isothermal rolled sheets is about 40% higher in orientations of 0° and 90° to rolling direction than that of the cold rolled sheets because of subgrain structures.

(3) The low ductility of 0° to rolling direction on the isothermal rolled sheets seems to reduce drawability at room temperature. The warm drawability of the isothermal rolled sheets improves and is superior to the cold rolled sheets.

Acknowledgements

This work was supported in part by a research fund of the project on “Aluminum production and fabrication technology development useful for automotive light-weighting” provided by the New Energy and Industrial Technology Development Organization (NEDO). The authors wish to express their gratitude to NEDO and the Japan Research and Development Center for Metal for their supports.

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